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OCEANIC STORM CHARACTERISTICS OFF THE KENNEDY SPACE CENTER COAST

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Abstract— **Natural cloud-to-ground lightning may behave differently depending on the characteristics of the attachment mediums, including the peak current (inferred from radiation fields) and the number of ground strike locations per flash. Existing literature has raised questions over the years on these characteristics of lightning over oceans, and the behaviors are not yet well understood. To investigate this we will obtain identical electric field observations over adjacent land and ocean regions during both clear air and thunderstorm periods. Oceanic observations will be obtained using a 3-meter NOAA buoy that has been instrumented with a Campbell Scientific electric field mill and New Mexico Tech's slow antenna, to measure the electric fields aloft. We are currently obtaining measurements from this system on-shore at the Florida coast, to calibrate and better understand the behavior of the system in elevated-field environments. Sometime during winter 2013, this system will be moored 20NM off the coast of the Kennedy Space Center. Measurements from this system will be compared to the existing on-shore electric field mill suite of 31 sensors and a coastal slow antenna. Supporting observations will be provided by New Mexico Tech's Lightning Mapping Array, the Eastern Range Cloud to Ground Lightning Surveillance System, and the National Lightning Detection Network. An existing network of high-speed cameras will be used to capture cloud-to-ground lightning strikes over the terrain regions to identify a valid data set for analysis. This on-going project will demonstrate the value of off-shore electric field measurements for safety-related decision making at KSC, and may improve our understanding of relative lightning risk to objects on the ground vs. ocean. This presentation will provide an overview of this new instrumentation, and a summary of our progress to date.**

Keywords—Lightning, electric fields, buoy

I. INTRODUCTION

The NASA Kennedy Space Center (KSC) sits in one of the country's highest lightning density locations, yet has responsibility for ensuring adequate weather support to Expendable Launch Vehicles, human space flight operations, and ground processing activities. NASA also ensures that operational weather requirements are considered during program/project development and are properly implemented, as well as ensuring that the weather infrastructure at operational sites are adequate to meet customer requirements. To meet these requirements, KSC and the Air Force Eastern Range (ER) have one of the most extensive collection of lightning detection systems in the world. We use data from two cloud-to-ground (CG) lightning detection networks, the Cloud-to-Ground Lightning Surveillance System (CGLSS) and the U.S. National Lightning Detection Network™ (NLDN), and a network of high speed cameras to monitor and characterize lightning that is potentially hazardous to launch or ground operations. We use a "Lightning Detection and Ranging" (LDAR) network to provide operational support for both ground and launch safety. We will also be installing a lightning mapping array (LMA) in 2014.

This extensive collection of networks, coupled with the high lightning incidence, provides the perfect environment to further our understanding of natural cloud-to-ground lightning. Natural lightning has not been well studied over the ocean and may well behave differently depending on the characteristics of the attachment mediums, including (at least) the peak current (inferred from radiation fields) and the number of ground strike locations per flash. This could have significant impact on the interpolation of lightning risk to objects on the ground. The observational domain for KSC instrumentation provides a broad range of electrical conductivity and terrain features (salt water, flat water, rolling hills, tall structures) for exploring these effects in an objective manner. This paper will outline the proposed method we will take to research the multiplicity, peak current and number of attachment points in near shore oceanic lightning strikes. We will be using the combination of our LMA, LDAR, and CGLSS networks along with the network of high-speed cameras to capture cloud-to-ground lightning strikes over the

various terrain regimes. We will be instrumenting the NASA owned NOAA buoy 41009 with both a Campbell Scientific (CS) 110 field mill and a New Mexico Tech slow antenna for electric field measurements 20nm off-shore,

Figure 1. NOAA buoy 41009 instrumented prior to deployment.

II. INSTRUMENTATION

The CGLSS is a local network that covers the KSC-ER operations area with 4 medium gain IMPACT ESP sensors[1] and 2 medium, gain LS7001 sensors[1] located 10 to 30 km apart (see Figure 2). The CGLSS processes data in the following sequence: sensors detect an electromagnetic pulse that is characteristic of a return stroke in CG lightning; the GPS time, amplitude, polarity, and direction of the stroke are transmitted via land-line communications to a network control center at the ER; information derived from multiple sensors is used to geo-locate the event and estimate the peak current (and polarity) of each stroke; and finally lightning information is forwarded to users in real-time via terrestrial data links. The CGLSS sensor locations are shown in Figure 2. The flash detection efficiency of the CGLSS inside the perimeter of the network is ~98% and the median location accuracy is ~250m (Boyd, et al, 2005, Mata et al, 2014).

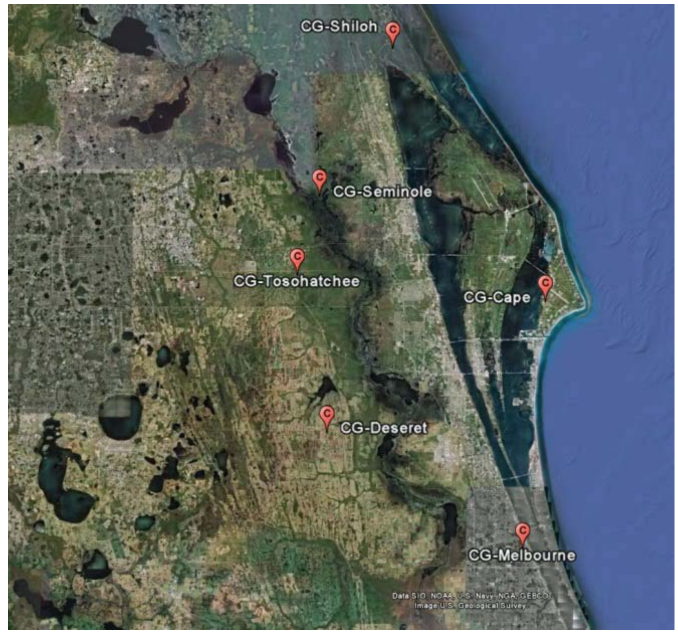

Figure 2. Locations of the CGLSS sensors (triangles) at the KSC-ER (Roeder 2012).

The NLDN is a national network of 113 IMPACT ESP sensors that are placed 200-350 km apart. Figure 3 shows the evaluation region (100 km radius) at the KSC-ER and its location relative to the 10 closest NLDN sensors (black triangles). The three closest NLDN sensors to the KSC-ER are in Palm Bay, Tampa, and Ocala, FL. The NLDN data processing steps are similar to the CGLSS, except that satellite links are used instead of land-line communications and the control center is located in Tucson, AZ. The entire process takes approximately 30-40 seconds. The NLDN flash DE is typically greater than 90%, and the median location accuracy is typically better than 500 m. Performance falls off somewhat at the boundaries of the network (Cummins et al., 2006; Cummins and Murphy, 2009).

Figure 3. Locations of the NLDN sensors (Cummins et al, 1998)

[1] Manufactured by Vaisala Inc., Tucson, AZ

The CS 110 Electric Field Meter (EFM), pictured in Fig. 4, measures the vertical component of the electric field, or fields aloft, by means of a rotating grounded shutter at various rates from 1 sample per 10 sec up to 5 samples per second. For this research we are using a variable rate of 1 sample per 10 sec during clear skies below +/- 500 V/m and 1 sample per sec during elevated fields above +/- 500 V/m. The CS110 processes data through an embedded CR1000 Datalogger that can communicate direct to a PC or remote through the RS-232 port connection, which we are using for this project (Campbell Scientific manual, 2012). The data is transmitted via Iridium modem, accumulated into 30 min bins and sent to the National Data Buoy Center (NDBC). NDBC then creates daily files for archival. http://dods.ndbc.noaa.gov/nasa/

Figure 4. CS110 (Campbell Scientific manual available at http://s.campbellsci.com/documents/us/manuals/cs110.pdf)

The New Mexico Tech Slow Antenna (pictured in Fig. 5) measures changes in electric field, but at a rate of 1000 samples per second. A slow antenna consists of a flat metal plate and records the voltage proportional to the electric field at the surface of the plate (NMT manual, 2012). There is currently no way to remotely receive data, but up to 10kHz-sampled data can be stored on 2 256GB SD cards. We will therefore be retrieving the data quarterly to insure no data loss.

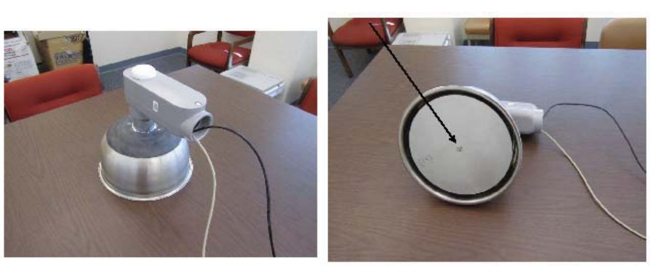

Figure 5. Slow Antenna (provided by D. Rodeheffer, unpublished manual, 2012)

The KSC LC39B lightning instrumentation system captures lightning strike video from 8 3200+ fps cameras (shown in Fig. 6) located at LC39B (6) and the Vehicle Assembly Building (2). The viewing angles from the 6 LC39B cameras are shown in Fig 7. The cameras operate and transmit using high speed, fiber optic isolated digitizers, installed on the field as close as possible to the dH/dt sensors that connect to a transient recorder at a central location. The transient recorder controls and configures digitizer, including its dynamic range and input coupling. Configuration management is done from a remote computer. Qualified triggers are setup in the transient recorder, which time-stamp the qualified trigger events. A segmented, circular buffer allows for pre-trigger and post-trigger information to be saved. The transient recorder has a FIFO that stores the data after a qualified trigger is observed and immediately starts transferring the data to the controlling computer. This architecture allows for no dead time between events resulting on a detection efficiency of 100 %, as long as the number of triggers in a second does not exceed 100. This is accomplished by defining a time acquisition window of at least 10 ms (Mata et al. 2010).

Figure 6. 3260 fps camera at LC39A facing SLC 41.

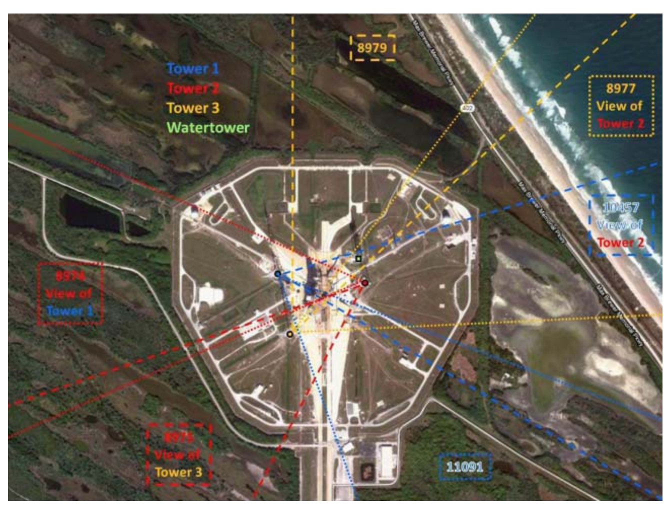

Figure 7. LC39B high-speed camera locations and viewing windows.

The KSC/Eastern Range Electric Field network is a large-area network of 31 electrostatic field sensors (field mills) that perform like the CS110, but are manufactured by Thunderstorm Technologies Inc. The sampling rate for all 31 sensors is 50 samples per second.

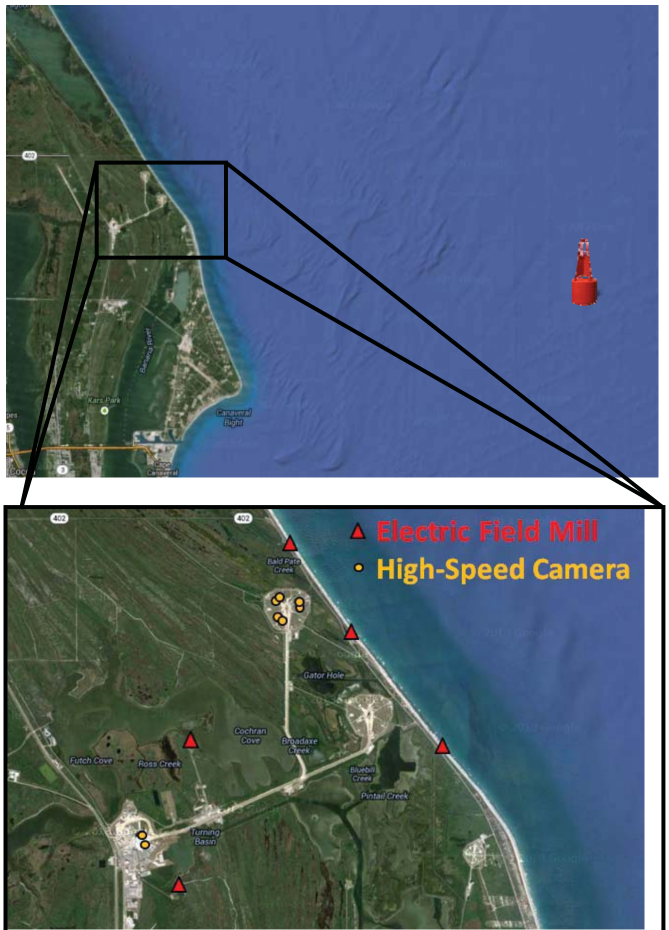

Figure 8. Buoy and Ground Instrumentation Locations

III. Methods

Lightning strike camera images were collected from the KSC LC39B lightning instrumentation system from 1/1/2011 – 12/30/2012 and manually reviewed to classify each event. The cameras captured 30 ms recordings with the interval between frames set at 312.5 µs.

Events were grouped into flashes, where a flash is defined as any stroke within 12km and 1sec from the first stroke, and logged with the following fields:

- Number of strokes
- Number of channels

Additionally, each stroke was logged with the following fields:

- Peak Current (Ip) (NLDN)
- Duration
- Shape of channel
- Root branching & multiple attach points
- M-components
- Closest field mill value with time <= 20 ms of the stroke time (and preceding the stroke time)

This study will test the hypotheses that natural lightning, as well as the associated electric fields over the ocean behave differently. Specifically, the peak current and fields aloft will be higher and the number of ground strike locations per flash will be statistically lower.

IV. Results

A. Buoy EFM Calibration

The mounting of the Campbell EFM on the buoy will impact its sensitivity (due to local grounded structures and elevation above the ground reference), as well as the highest static field values (due to the impact of local corona on the electrical conductivity of the environment near the EFM). In preparation for the buoy deployment 20nm off the KSC coast in February, a calibration test way conducted at the Maria Bray buoy yard in Atlantic Beach, FL. A frontal passage took place the evening of October 21, 2103. A Campbell Scientific calibration test stand Fig. 9) was placed 50 meters away from the instrumented buoy and run for a 3-day duration. The results, shown below, demonstrate near-perfect correlation between to 2 mills (Fig. 10) once a sensitivity-correction scaling of 0.594 is applied to the buoy data (Fig. 11). Therefore, no additional modifications were needed for sea state preparations.

Figure 9. Calibration test set-up for electric field mill.

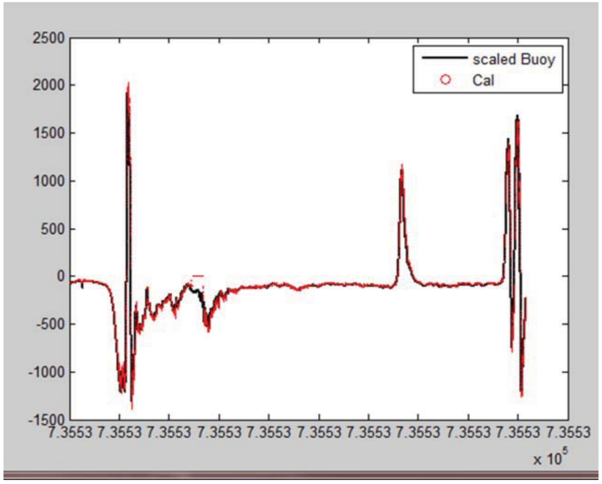

Figure 10. Calibration test through a frontal passage 10/22/13 0400 – 2300 GMT

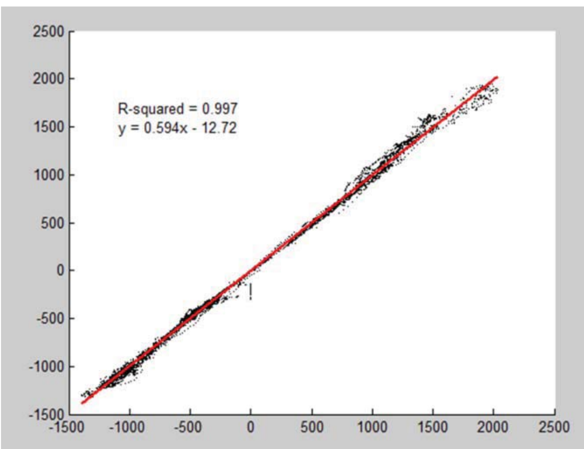

Figure 11. Correlation results from the calibration test 10/22/13 0400 – 2300 GMT

Once the field mill calibration results were known, the electric field values were reviewed for the entire period of time the buoy was a the coast guard station on the Atlantic Beach coast. For periods of time with close lightning activity, as determined by the NLDN, the EFM measurements were reviewed to confirm overall-reasonable behavior and proper time-correlation with NLDN CG strokes. The impact of corona was clear when fields exceeded roughly 4kV/m. This effective "saturation" of the static electric field occurs because the higher the surrounding fields becomes, the higher the corona currents from the structure. This in turn increases local air conductivity and decreases the electric field. (Vonnegut, 1984). This was a known potential problem, and one that should be somewhat reduced once the buoy in deployed and in the ocean. This will NOT prevent accurate determination of polarity and trend of the static field, but will impact the absolute magnitude of the field.

Two case studies are shown below. In the first, Figures 12a and 12b, a frontal passage with active lightning came directly overhead of the buoy on September 18, 2013. Fig. 12a shows the complete time-series for this storm. The orange "dots" show the distance in km to the closest NLDN report for each minute (right-had vertical axis). During the period from 1300 to 1400 GMT, when the lightning was the closest, the field mill experienced corona effect suppressing the reading to between 4-5kV/m. It is therefore unknown how high the fields truly were. Fig. 12b is a zoom-in on a 20-minute period as the storm gets close to the EFM, and includes individual NLDN reports at their respective distances. The green circles are negative CG return strokes, and the black "dots" are cloud pulses.

During the second case study, Figure 13, a frontal passage with active lightning passed within 40km of the buoy on November 2, 2013, but no clear corona effect was noted. Fields on this day naturally reached up to 5kV/m.

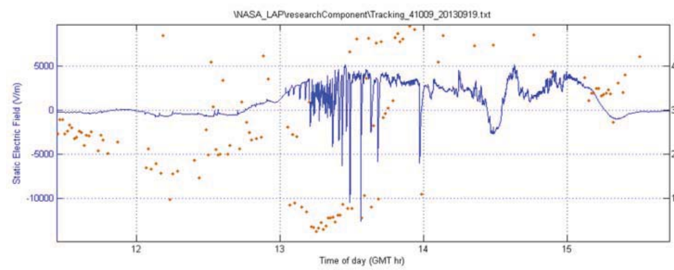

Figure 12a. 9/18/13 storm passage where the corona effect was noted between 1300 and 1400 GMT.

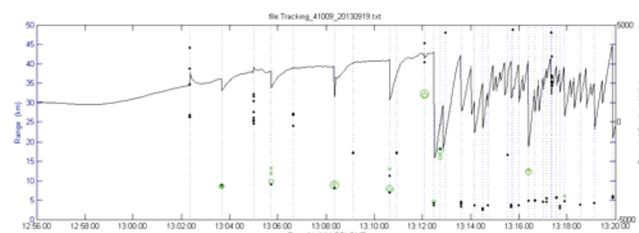

Figure 12b. 9/18/13 storm passage where the corona effect was noted between 1300 and 1400 GMT.

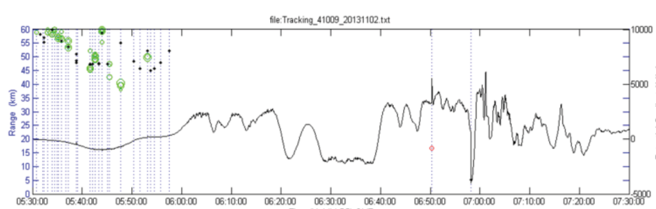

Figure 13. 11/2/13 storm passage with no corona effect.

B. Ocean vs. Land Stroke Characteristics

For the 2-year period of gathered data from the KSC/ER high-speed camera network, 487 strokes were captured in at least on camera frame. There were a total of 222 strokes captured over the ocean, and 266 strokes over land.

Preliminary results have shown no bias in multiplicity, duration, or channels. 2 categories worth mentioning though are Peak Current (Ip) and fields aloft. Though a larger sample size and area needs to be examined, the authors have found the highest Ip occurring over the ocean as well as the higher electric fields. A sample case study is shown below. A storm passed directly over the KSC on October 10, 2011. Figures 14a,b, and 15 show a stroke that occurred at 02:45:59.949 UTC. It was the first stroke out of a 7 stroke flash that discharged near-shore into the Atlantic Ocean and had a Ip of -282.6 kA. The electric field recorded from the closest field mill 4km away was -3376 V/m. The same storm produced a single stroke flash that discharged over land 2 minutes later at 02:47:06.475 UTC and had a Ip of -124.2 kA. This event is shown in Figures 16a,b, and 17. The electric field recorded from the closest field mill 1.2km away was -1524 V/m. This is a classic example of the findings to date in the dataset; higher fields readings over the ocean during active lightning.


Figure 14a. 10/10/2011 02:45:59.959 UTC -282.6 Ip Ocean Stroke

Figure 14b. Clear Sky view of figure 14a.

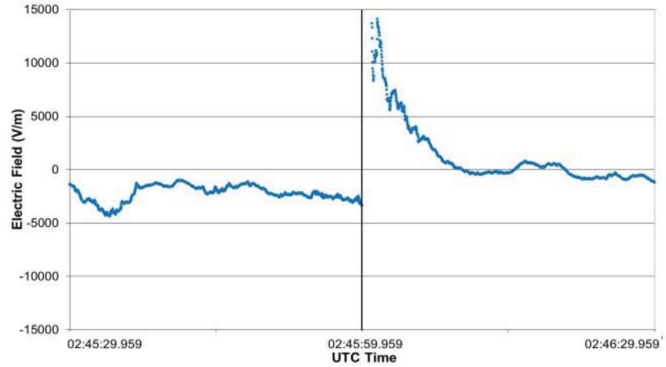

Figure 15. 10/10/2011 02:45:59.959 UTC -3376 V/m E-field measured 4.104 km from Stroke


Figure 16a. 10/10/2011 02:47:06.475 UTC -124.2 Ip Ground Stroke

Figure 16b. Clear sky view of figure 16a.

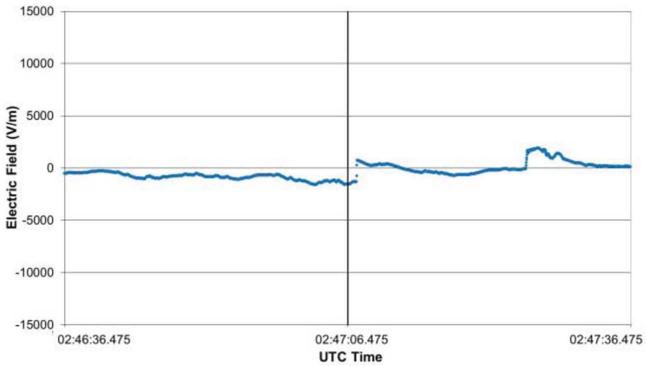

Figure 17. 10/10/2011 02:47:06.475 UTC -1525 V/m E-field measured 1.199 km from Stroke

V. Discussion and Future Work

The NDBC CS110 performed near uniformly with the CS110 calibration test stand through a 3-day period before, during, and after a frontal passage. Some corona effects were noticed when electric fields over the buoy instrumentation exceeded around 4kV. This issue should be reduced once the buoy is deployed.

A total of 487 strokes have been reviewed from KSC's High Speed Camera network from 2011-2012; 222 over ocean and 266 over land. The largest Ip in this sample originate over the ocean but no conclusion can be made to date whether oceanic storms produce statistically larger Ip.

Preliminary results also show higher E-fields over ocean during active lightning as compared to on-shore E-fields using the same criteria. Both of these discoveries can be further studied once the instrumented buoy is deployed in February 2014. Once deployed, fields will be monitored continuously and compared to on-shore mills to compare elevated field levels during active storms passing from on-shore to off-shore in the east central Florida region.

Acknowledgment

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